The Research of Capillary Pressure in the Process of CO_2 Displacement in Low-Permeability Reservoir

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Abstract: The function of capillary pressure in the process of CO_2 displacement in low-permeability reservoir is researched through combination of indoor experiments and numerical simulation. On the basis of different displacement experiments in long core chamber, one-dimensional numerical simulation component model is built to research the function of capillary pressure under the different CO_2 displacement ways. The results show that the capillary pressure under the different CO_2 displacement ways is not consistent. Capillary pressure is the driving force in the process of CO_2 displacement while resistance force in the process of CO_2 pressure buildup and displacement. In order to promote reasonable and efficient development of low-permeability reservoirs, it is suggested that further study about microscopic effects and laws of the capillary pressure in the reservoir should be done through experiment.

Keywords: Carbon dioxide, Capillary pressure, Displacement, Low-permeability reservoir, Numerical simulation.

1. INTRODUCTION

Rocks show different wettability for different reservoir properties and fluid properties, thus the value and function of the capillary pressure are different [1-7]. In low-permeability reservoirs, because of the existence of start-up pressure gradient, the seepage law is different from conventional medium and high permeable reservoirs [8-10]. When developing low permeable reservoir with CO_2 injection, there are a variety of displacement ways [11-15]. At present, in different displacement processes, researches on the function of the capillary pressure are little, even often be neglected. In this paper, combining indoor experiment and numerical simulation methods, the function of the capillary pressure in the process of CO_2 displacement in low-permeability reservoirs are researched.

2. THE FUNCTION OF CAPILLARY PRESSURE IN CO_2 DISPLACEMENT EXPERIMENTS

2.1. The Establishment of Indoor Experiments Scheme and Numerical Simulation Model

A total of 22 cores with total length of 973.44 mm are adopted in the experiment with Bragg sequence method. Harmonic-mean permeability is $2.261\times10^{-3}\mu m^2$ and the average diameter is 25.39 mm. Related parameters are shown in Table **1**. In displacement experiments, CO_2 is injected into the long core with a rate of 0.5 ml/min.

A horizontal ID numerical simulation component model is used in numerical simulation with grid number of 110. Simulation grids are shown in Fig. (**1**).

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Table 1. Core parameter of experiments (test7).

Saturated Water Volume (Pore Volume) , ml	The Volume of Saturated Oil, ml	Oil Saturation, %	Irreducible Water Saturation, %
49.5	32.1	64.85	35.15

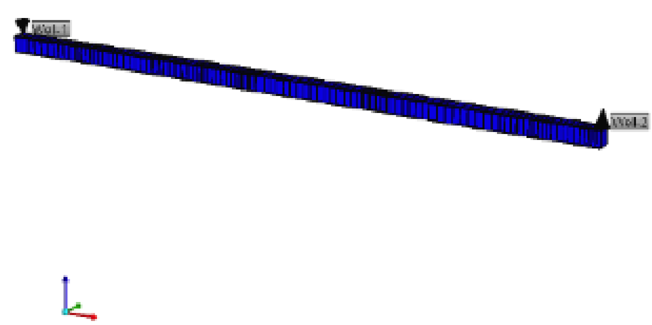

Fig. (1). One-dimensional model diagram.

2.2. Research of Capillary Pressure Function

Capillary pressure is common in low-permeability reservoirs. The function of capillary pressure is different in various reservoirs and it is one of the important factors in oil and gas seepage. Based on history match of the experimental data, through change of the capillary pressure, numerical simulation study is done and the sensitivity is studied. The simulation results are shown in Table **2**. From cumulative oil production rate and recovery degree, it is indicated that the higher the capillary pressure is, the higher the cumulative oil production rate and recovery degree are, and the capillary pressure is driving force.

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Table 2. Sensitivity analysis of capillary pressure.

Item	Cumulative Oil Production, g	Recovery Degree, %
Experimental data	10.96	39.78
Increase capillary pressure	11.18	40.59
Decrease capillary pressure	10.60	38.49

2.2.1. The Influence of Decreasing Capillary Pressure

Decrease the capillary pressure to a quarter of original value (test7-cp-1), as shown in Fig. (**2**). The impact of decreasing capillary pressure on oil production rate is shown in Fig. (**3**) and Table **2**. The results indicate that the peak oil production rate decreases with the decrease of capillary pressure, also the time appearing peak oil production rate delays (peak oil production rate decreases from $6.8\times10^{-4}m^3/d$ before reducing capillary pressure to $4.25\times10^{-4}m^3/d$, the time appearing peak oil production rate delays from 0.047 days to 0.063 days).

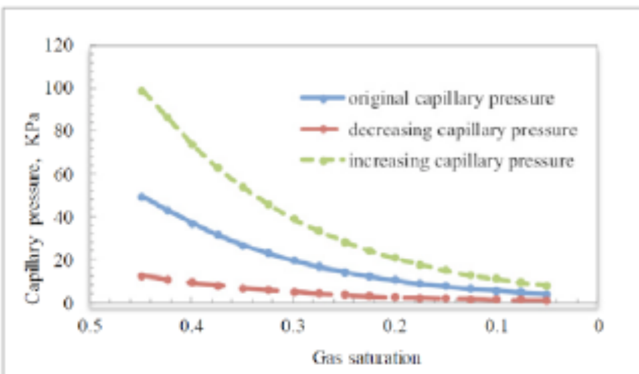

Fig. (2). Capillary pressure curve.

Analyzing simulation results, the capillary pressure is the driving force in the experiments. Decreasing the capillary pressure, the driving force of CO_2 decreases, and the injection velocity of CO_2 decreases, the contact area and dissolve degree of CO_2 and oil decreases, then the swept area and the displacement efficiency decreases. Therefore the cumulative oil production rate decreases compared with the condition of not decreasing capillary pressure.

2.2.2. The Effect of Increasing Capillary Pressure

Capillary pressure increases 2 times of the original value (test7-cp-2), as shown in Fig. (**2**). The impact on oil production rate is shown in Fig. (**4**) and Table **2**. Along with the increase of capillary pressure, the peak production rate decreases, the time appearing peak production rate advances (peak oil production rate decreases from $6.8\times10^{-4}m^3/d$ before increasing capillary pressure to $3.94\times10^{-4}m^3/d$, the time appearing peak oil production rate advances from 0.047 days to 0.038 days).

Simulation results further indicate that the capillary pressure is driving force. Increase of capillary pressure leads to the increases of driving force in CO_2 injection, and the increases of CO_2 injection rate into the core, also the increases of contact area and dissolve degree between CO_2 and oil. Then the swept area and displacement efficiency increases, therefore the cumulative oil production rate increases compared with the condition of not increasing capillary pressure.

3. THE RESEARCH OF CAPILLARY PRESSURE IN THE PROCESS OF CO_2 PRESSURE BUILDUP AND DISPLACEMENT EXPERIMENTS

3.1. The Experiment Scheme of Pressure Buildup and Displacement Experiments

Basic data of core is the same with displacement experiment, other parameters are shown in Table **3**. In the experiment, gas is injected into the core with a certain injection

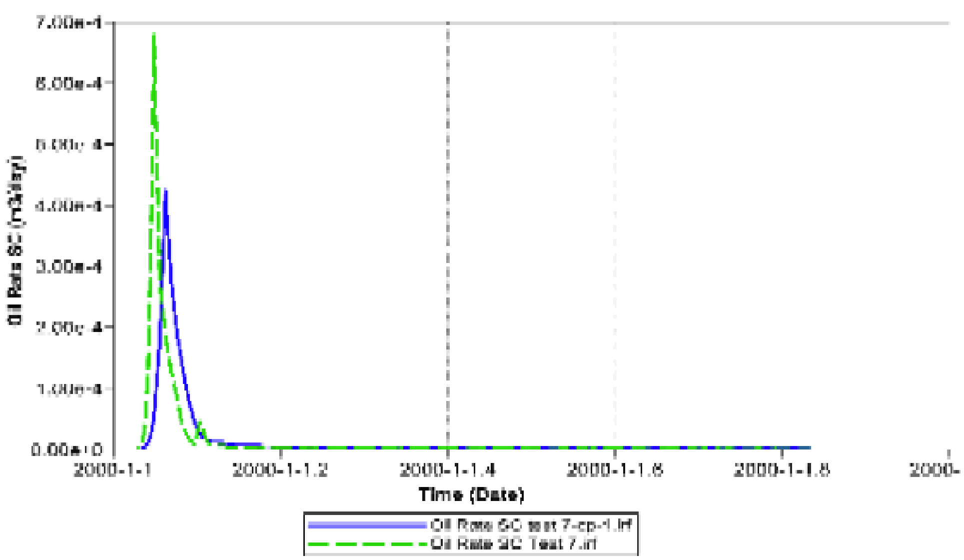

Fig. (3). Oil production rate comparison when decreasing capillary pressure (note: due to the timing unit of experiments is in minutes, the date on X-axis is expressed with a decimal point).

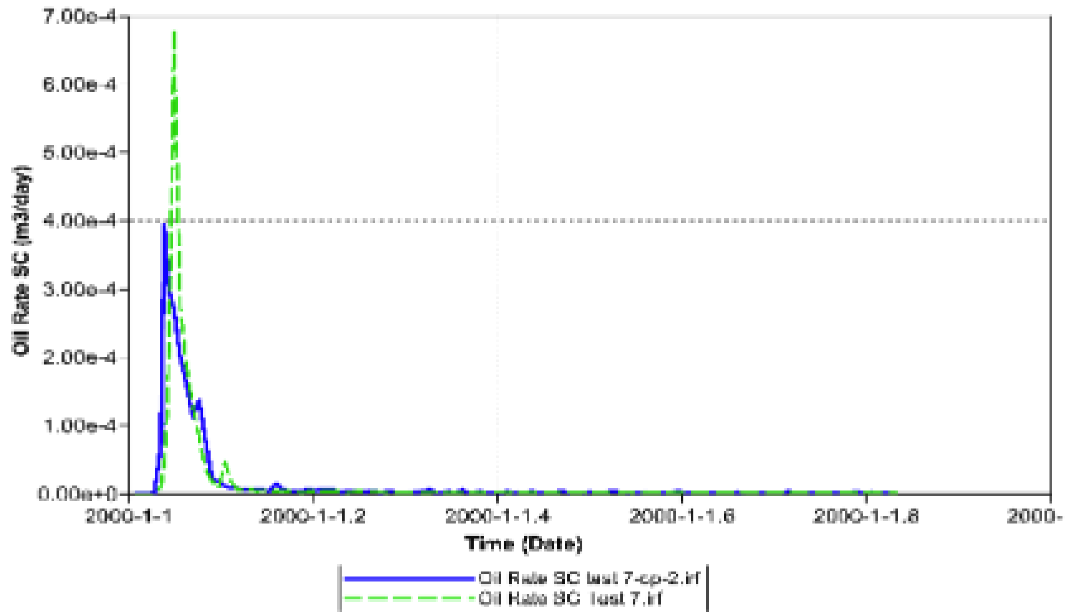

Fig. (4). Oil production rate comparison when increasing capillary pressure.

rate in the early 442 minutes. When the pressure reaches up to 20 MPa, CO_2 is rejected into the core with a rate of 0.5 ml/min, and then CO_2 displacement process is implemented in the experiment.

Table 3. Core parameter of pressure buildup displacement experiment (test8).

Saturated Water Volume (Pore Volume) ml	Saturated oil Volume ml	Oil Saturation %	Irreducible Water Saturation %
48.20	31.90	66.18	33.82

3.2. Research on Capillary Pressure Function

Based on history match of the experimental data, through change of the capillary pressure, numerical simulation study is done and the sensitivity is studied. The simulation results are shown in Table **4**. From cumulative oil production rate and recovery degree, it is indicated that the higher the capillary pressure is, the lower the cumulative oil production rate and recovery degree are, and the capillary pressure is resisting force.

Table 4. Sensitivity analysis of capillary pressure.

Item	Cumulative Oil Production, g	Recovery Degree, %
Experimental data	13.64	49.84
Increasing capillary pressure	12.99	47.46
Decreasing capillary pressure	13.73	50.16

3.2.1. The Effect of Decreasing Capillary Pressure

Decrease the capillary pressure to a quarter of original value (test8-cp-1), as shown in Fig. (**5**). The impact of decreasing capillary pressure on oil production rate is shown in Fig. (**6**) and Table **4**. The results indicate that cumulative oil production rate increases a little along with the decrease of capillary pressure. The peak oil production rate and the time appearing peak oil production rate are the same (peak oil production rate is $6.57\times10^{-4}m^3/d$ and the time appearing peak oil production rate is 0.356 days).

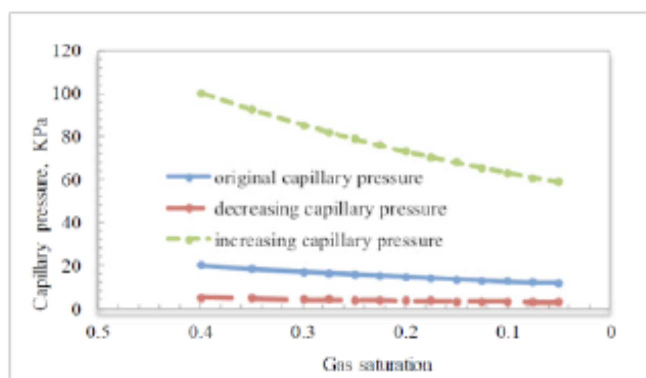

Fig. (5). Change of capillary pressure curve.

Analyzing simulation results, the capillary pressure is resistance force in the experiments. Decreasing the capillary pressure, the resistance force of CO_2 decreases, and the injection velocity of CO_2 increases, the contact area and dissolve degree of CO_2 and oil increases, then the swept area and the displacement efficiency increases. Therefore the cumulative oil production rate increases compared with the condition of not decreasing capillary pressure.

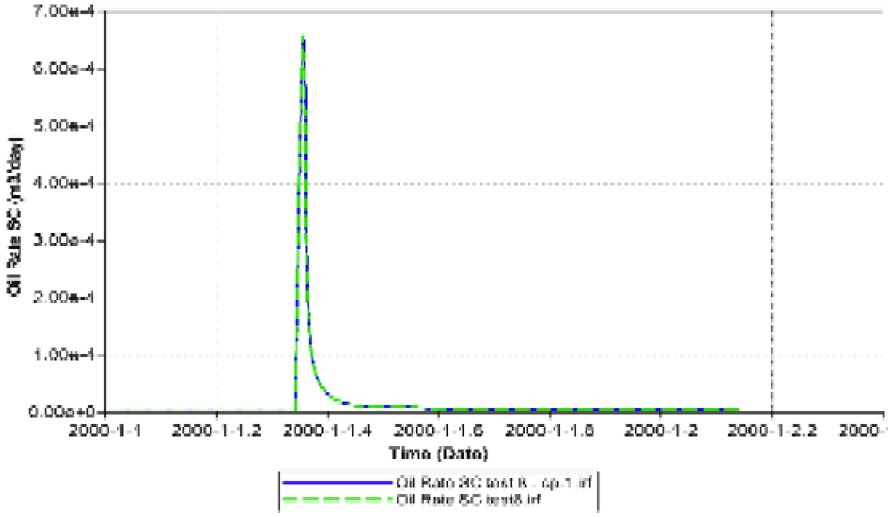

Fig. (6). Oil production rate comparison when decreasing capillary pressure.

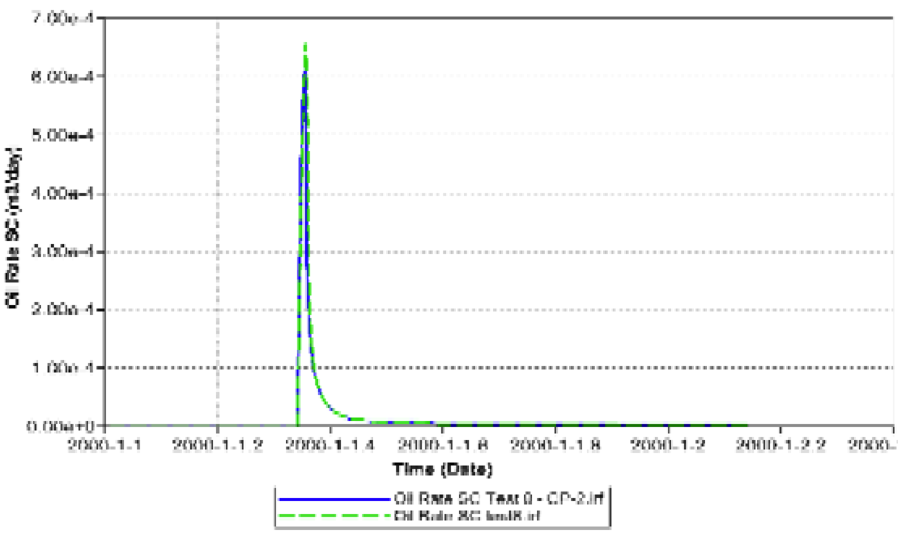

Fig. (7). Oil production rate comparison when increasing capillary pressure.

3.2.2. The Effect of Increasing Capillary Pressure

Capillary pressure increases to 5 times of original value (test8-cp-2), as shown in Fig. (**5**). The impact on oil production rate is shown in Fig. (**7**) and Table **4**. Along with the increase of capillary pressure, the peak production rate decreases, the time appearing peak production rate is the same (peak oil production rate decreases from $6.57\times10^{-4}m^3/d$ before increasing capillary pressure to $6.09\times10^{-4}m^3/d$, the time appearing peak oil production rate is 0.356 days).

Simulation results further indicate that the capillary pressure is resistance force. Increase of capillary pressure leads to the increases of resistance force in CO_2 injection, and the decreases of CO_2 injection rate into the core, also the decreases of contact area and dissolve degree between CO_2 and oil. Then the swept area and displacement efficiency decreases, therefore the cumulative oil production rate decreases compared with the condition of not increasing capillary pressure.

CONCLUSION

1. Capillary pressure is the driving force in the process of CO_2 displacement. Along with the increase of capillary pressure, the time appearing peak production rate advances, the cumulative oil production rate increases. It is mainly because the driving force enhances CO_2 injection ability and improves the displacement efficiency of CO_2.
2. Capillary pressure is resistance force in the process of pressure buildup and CO_2 displacement. Along with the increase of capillary pressure, peak oil production rate and the cumulative oil production rate decreases. It is mainly because the resistance force decreases CO_2 injection ability and reduces the displacement efficiency of CO_2.
3. In the low-permeability reservoir, the capillary pressure appears in different forms in the process of CO_2 displacement. In further research, it is suggested that microscopic effects and laws of the capillary pressure in the reservoir should be done through experiments.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

ACKNOWLEDGEMENTS

Declared none.

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Received: April 17, 2015 Revised: May 21, 2015 Accepted: May 26, 2015